Experiment Station. The maximally effective sediment cap being considered would be 45-cm thick and cover 7.6 km^2 of soft bottom (Palermo et al. 1999). Palermo et al. (1999) conclude that the shelf area lying between the 40- and 70-m depth contours could be capped without needing special control measures. The 7.6-km^2 cap would have 4.9 km^2 centered over the "hot spot" of highest contamination and 2.7 km^2 located northwest of the "hot spot." The cap would not be placed on the PV slope (because of the steepness of the slope) or over other areas with lower contaminant concentrations.

Table 14. White croaker injuries with an effective sediment cap.
Cap effectiveness estimated by reducing standing stocks in segments 5-9 at 30-100 m by 50.6%.

	Segment Number									
	3	4	4.5	5	6	7	8	9		
Prop. of fish exceeding threshholds										
1992-1999 (> 30 m)										
0.1 ppm	**1.0**	*1.0*	**1.0**	*1.0*	*1.0*	**1.0**	no data	no data		
1992-1999 (< 30 m)										
0.1 ppm	no data	no data	no data	no data	**1.0**	**1.0**	no data	no data		
biomass/segment (kg)										
biomass density (kg/ha)										
1992-1999										
23 m	0.032	0.075	0.075	0.075	0.31	0.31	0.31	0.481		
61 m	0.16	1.059	1.059	1.059	12.16	12.16	12.16	0.663		
137 m	0	2.107	2.107	2.107	0.021	0.021	0.021	4.23		
area/segment (ha)										
<30 m	1008	333	250	181	221	254	197	181		
30-100 m	1022	1458	414	317	267	355	303	259		
100-200 m	710	448	146	83	114	77	74	71		
Biomass/segment (kg)										
1992-1999										
<30 m	32	25	19	14	69	79	61	87		
30-100 m	164	1,544	438	170	1,643	2,184	1,864	87		
100-200 m	0	944	308	175	2	2	2	300		
TOTAL	196	2,513	765	358	1,714	2,265	1,927	474		
TOTAL YEARLY BIOMASS EXCEEDING THRESHOLD (kg)										TOTAL
1992-1999 (> 30 m)	164	2488	746	345	1645	2186				7,573
1992-1999 (<30 m)					69	79				147

To calculate the potential reduction in fish injuries in the presence of an effective sediment cap, I assume that the cap would result in effective containment of DDT in the sediments that are capped and that fish do not move away from the capped area to acquire contaminants elsewhere. I calculate the potential reduction by calculating the standing stock of fish in the area that would be capped and assuming they would be "clean" (i.e., above the California State trigger level). The sediment cap would mainly be located in segments 5-9, so biomass densities from those segments are used. The sediment cap would be located mainly between 40 and 70 m depths, so biomass densities for the 30-100 m depth zone were used. The total area of the 30-100 m depth zone in segments 5-9 is 1501 ha, or 15 km^2. Therefore, the sediment cap would cover 50.6% of entire area in that region. If the cap results in "clean" fish above it, then 50.6% of the standing stock in that region would be clean. I calculate the potential effectiveness of the cap by removing 50.6% of the fish from the 30-100 m depth zone in segments 5-9. I include only the data from 1992-99 as the best estimates for current (and future) standing stocks.

With an effective cap, the yearly standing stock of white croaker exceeding 0.1 ppm is expected to be 7,721 kg for 1992-99 (Table 14), compared to 11,623 kg without a cap (Table 1). The yearly standing stock Dover sole exceeding 0.1 ppm with an effective sediment cap is estimated to be 11,220 (Table 15), compared to 11,595 without a cap (Table 2). For both species combined, the yearly standing stock exceeding the California State trigger level with a cap is estimated to be 18,940 kg, compared to 23,218 kg without a cap, for a reduction of 18% due to the effectiveness of the cap. Under the assumptions described above, an artificial reef must support **18,940** kg of fish to provide primary restoration.

Table 15. Dover sole injuries with an effective sediment cap.
Cap effectiveness estimated by reducing standing stocks in segments 5-9 at 30-100 m by 50.6%.

	Segment Number									
	3	4	4.5	5	6	7	8	9		
Prop. of fish exceeding threshholds										
1992-1999										
	1.0	*1.0*	**1.0**	*1.0*	*1.0*	**1.0**	no data	no data		
biomass/segment (kg)										
biomass density (kg/ha)										
1992-1999										
23 m	0	0	0	0	0	0	0	0		
61 m	0.449	0.428	0.428	0.428	1.005	1.005	1.005	0.984		
137 m	2.855	9.133	9.133	9.133	7.144	7.144	7.144	10.352		
area/segment (ha)										
<30 m	1008	333	250	181	221	254	197	181		
30-100 m	1022	1458	414	317	267	355	303	259		
100-200 m	710	448	146	83	114	77	74	71		
Biomass/segment (kg)										
1992-1999										
<30 m	0	0	0	0	0	0	0	0		
30-100 m	459	624	177	69	136	181	154	129		
100-200 m	2,027	4,092	1,333	758	814	550	529	735		
TOTAL	2,486	4,716	1,511	827	950	731	683	864		
TOTAL YEARLY BIOMASS EXCEEDING THRESHOLD (kg)										TOTAL
1992-1999	2,486	4,716	1,511	827	950	731				11,220

5.1.2. Primary restoration in the absence of an effective sediment cap

It is possible that no cap will be placed over contaminated sediments, or that the cap will be significantly different is size or design than the one considered in the previous section. It is also possible that any cap may not reduce exceedances in fish. Therefore, I consider the standing stock of fish needed to provide primary restoration in the absence of an effective sediment cap. This standing stock is estimated as the present standing stock of fish that exceeds the 0.1 ppm trigger level. The 1992-99 standing stock is the best estimate for current (and future) standing stocks. The average standing stock that exceeded the 0.1 ppm target level in 1992-99 was 11,623 kg for white croaker and 11,595 kg for Dover sole, for a total of **23,218** kg. This is the standing stock that would need to be provided by an artificial reef to provide primary restoration in the absence of an effective sediment cap.

5.2. Compensatory restoration

Compensatory restoration will provide resources to compensate for damages that have occurred since 1981. The amount of damages was determined using a Resource Equivalency Analysis, as described in the next section.

5.2.1. Resource Equivalency Analysis

Table 16 shows the inputs used for the Resource Equivalency Analysis model. In this analysis, a discount rate of 3% was used, damages were calculated from 1981 to 2005 (and no cap was included).

The model inputs for the artificial reef include construction of the reef by 2005, 4 years to reach full population standing stocks, and a 100-year lifespan. The time of construction of the reef was chosen to be the earliest possible year. Even with a decision to construct a reef immediately, public hearings, detailed engineering and biological studies (including surveys of physical and biological characteristics of potential reef sites), environmental impact assessments, and permitting would take several years. Contracting such a large, complex reef project would also take an extended period of time, and construction would likely occur over several years. If the reef in not built before 2005, then a larger reef will be needed to compensate for the damages. For example, if the reef is not built until 2010, then it would have to have a standing stock of 46,085 kg rather than 39,750 kg to provide full compensation.

The development of fish standing stocks on existing artificial reefs indicates that four years is a reasonable estimate for how long it takes for fish standing stock to develop fully on a new artificial reef. However, there are also reasons to believe it might take longer than 4 years for the full standing stock to develop (see Section 0). If the reef takes 10 years instead of 4 years to develop its standing stock, then the reef would have to have a standing stock of 43,530 kg rather than 39,750 kg to provide full compensation. (Obviously, if both the construction and the development of standing stock on the reef are delayed, an even larger reef would be required. If construction begins in 2010 and it takes 10 years for the full standing stock to develop, then the reef would have to have a standing stock of 50,465 kg for full compensation.)

Finally, I have used a reef lifespan of 100 years. There is little evidence upon which the lifespan of the reef can be determined. The earliest artificial reefs *per se* in California were built in the late 1950s, but the materials used differ from modern artificial reefs and they have not persisted. One "artificial reef" that has lasted 100 years is the LA Breakwater. However, the breakwater is a unique structure, and some factors that would affect more traditional artificial reefs, such as sedimentation, would not affect it. The earliest "rockpile" reefs were built in the mid-1970s (e.g., Torrey Pines Artificial Reef was built in 1975). These reefs, which are now about 25 years old, show little sign of deterioration. The quarry rock used for rockpile reefs should have an extremely long life (although other materials might not last as long). Rather than destruction of the base material, the main limits to reef lifespan will be severe storms, subsidence, sedimentation, or other large-scale physical processes. The primary and compensatory restoration reefs will likely be placed in an environment (shallow, on soft-bottom habitat, etc.) where these factors could limit their lifespans. With the multitude of uncertainties about a reef's maximum lifespan, along with a lack of experience in California with artificial reefs of such age, 100 years is a reasonable estimate for how long an artificial reef might be expected to persist and provide a reasonable standing stock of fish. However, it could also be less than 100 years. If the reef's lifespan were only 50 years, then it would need to have a standing stock of 49,355 kg instead of 39,750 kg in order to provide full compensation.

Table 16. Resource Equivalency Analysis model inputs and summary of results.

Model Inputs	
Discount Rate:	0.03
Base Year	2000
Form of Restoration Productivity Growth	Linear
Year FDA Level Begins to be Exceeded	1981
Year State Level Begins to be Exceeded	1992
Final Year FDA Level Exceeded	1991
Final Year State Level Exceeded	2005
Reef Inputs	
Year Benefits Begin to Accrue	2005
Years to Reach Full Population	4
Biomass at Full Population (Kg)	39,750
Lifespan of Reef (Years)	100

Summary of Resource Equivalency Analysis Results			
Period Exceed FDA Levels	1981	to	1991
Total Biomass Exceed FDA Level	335,776 kg-yr		
Period Exceed State Levels	1992	to	2005
Total Biomass Exceed State Level	698,826 kg-yr		
Total Biomass Exceeding Thresholds	**1,034,602** kg-yr		
Biomass from Reef	1,034,513 kg-yr		

In the calculation of damages, it is assumed that injuries cease completely in 2005 because the reef will have been producing enough clean biomass. Actually, injuries will cease when the primary restoration reef has been constructed and reached its target standing stock. As noted above, it is quite likely that construction will commence later than 2005 because of the need for detailed engineering studies, public hearings, environmental impact assessments, and permitting. I have used 2005 as a conservative estimate of damages. In the REA I also have considered that damages cease immediately when reef construction begins, rather than allowing for a gradual build-up of standing stock, as would actually occur. This leads to a lower (conservative) estimate of damages.

Table 16 also presents a summary of the results of the Resource Equivalency Analysis. The total biomass exceeding thresholds is 1,034,602 kg-yr, 335,776 kg-yr from exceeding the FDA level and 698,826 kg-yr from exceeding the state level. Details of the calculation of damages are given in Table 19 in Appendix 1.

Assuming the artificial reef parameters stated above, the reef must support a standing stock of 39,750 kg of sport fish in order to provide compensatory restoration. Details of the benefits calculations are given in Appendix 1.

6.0 Artificial reef project

This section describes the artificial reef project required as restoration for the fish injuries considered in this report. Although the primary and compensatory reefs could be part of one reef, they are considered separately here for conceptual simplicity.

Because the restoration reefs would be constructed on soft-bottom habitat, with rock habitat covering up the existing soft-bottom habitat, the reefs will displace soft-bottom fishes (including white croaker and Dover sole). I have not adjusted the size of the restoration reefs to account for the "loss" of the standing stock of soft-bottom fish currently occurring where the reefs would be constructed.

6.1. Primary restoration

Table 17 provides a summary of the specifications for an artificial reef needed to provide primary restoration. With a sediment cap that is as effective as currently envisioned by the U.S. Army Corps of Engineers, there will continue to be a standing stock of 18,940 kg of white croaker and Dover sole that exceed the 0.1 ppm trigger level. Assuming the biomass density of sport fish on an artificial reef would be 248 kg/ha, a 76-ha reef would be needed to provide an equivalent standing stock of clean fish. At $419,000/ha to construct, the primary restoration reef would cost approximately $32 million.

The size (and cost) of the primary restoration reef is sensitive to the estimate of sport fish biomass density to be gained by constructing the reef. The value of 248 kg/ha was based on the average of all estimates available for biomass density of artificial and natural reefs in southern California. However, estimates provided by John Stephens are substantially higher than all other estimates. If Stephens' estimates are excluded, the average biomass density is 193 kg/ha. With that biomass density, a 98-ha reef would be required to provide primary restoration if the cap is effective, at an estimated cost of $41 million.

Table 17. Specifications for artificial reef required for primary restoration.

	With effective cap	Without effective cap
Biomass exceeding 0.1 ppm	18,940 kg	23,218 kg
Biomass gain from reef		
Sport fish biomass density	248 kg/ha	248 kg/ha
Size of reef	76 ha	94 ha
Cost		
Cost per hectare	$419,000	$419,000
Total cost	$31,999,435	$39,227,185

If no sediment cap is put in place, or the cap is not effective, there will continue to be a standing stock of 23,218 kg of white croaker and Dover sole that exceed the 0.1 ppm trigger level. Assuming the biomass density of sport fish on an artificial reef would be 248 kg/ha, a 94-ha reef would be needed to provide an equivalent standing stock of clean fish. At $419,000/ha to construct, the primary restoration reef would cost approximately $39 million.

As noted above, the size (and cost) of the primary restoration reef is sensitive to the estimate of sport fish biomass density to be gained by constructing the reef. The value of 248 kg/ha was based on the average of all estimates available for biomass density of artificial and natural reefs in southern California. However, estimates provided by John Stephens are substantially higher than all other estimates. If Stephens' estimates are excluded, the average biomass density is 193 kg/ha. With that biomass density, a 120-ha reef would be required to provide primary restoration if the cap is not effective, at an estimated cost of $50 million.

6.2. Compensatory restoration

Table 18 provides a summary of the specifications for an artificial reef needed to compensate for damages since 1981. The standing stock needed for full compensation is 41,775 kg. Assuming that the artificial reef will have a biomass density of sport fish of 248 kg/ha, then a 160 ha reef is needed to provide the required standing stock. At $419,000/ha to construct, the compensatory reef would cost approximately $67 million.

Table 18. Specifications for artificial reef required for compensatory restoration.

Biomass at full population	39,750	kg
Biomass gain from reef		
Sport fish biomass density	248	kg/ha
Size of reef	160	ha
Cost		
Cost per hectare	$419,000	
Total cost	$67,158,266	

The size (and cost) of the compensatory restoration reef is sensitive to the estimate of sport fish biomass density to be gained by constructing the reef. As noted above, the value of 248 kg/ha was based on the average of all estimates available for biomass density of artificial and natural reefs in southern California. However, estimates provided by John Stephens are substantially higher than all other estimates. If Stephens' estimates are excluded, the average biomass density is 193 kg/ha. With that biomass density, a 206-ha reef would be required to provide compensatory restoration, at an estimated cost of $86 million.

6.3. Location and Design

The size of primary restoration and compensatory restoration reefs combined is 236 ha or 254 ha. This area is more than 50% of the total area of kelp beds around the Palos Verdes Peninsula (459 ha). It is not possible to specify precisely the location of such a large reef. In fact, it is likely that a number of separate reefs would be built in different locations. These reefs would be outside of the area of high DDT contamination but as close as possible to the Palos Verdes region. The most likely locations are Santa Monica Bay and downcoast of Long Beach Harbor.

I have not specified a particular design for the restoration reefs. The size of reef required would accommodate a number of different designs, including emergent reefs (like the King Harbor breakwater), shallow reefs near fishing facilities, and offshore reefs. Logistical constraints may limit some reef designs. For example, breakwater-like structures can affect long-shore sand movement, navigation, and other activities, so it might not be possible to build that type of design in Santa Monica Bay or downcoast of Long Beach Harbor. The design of the reefs would need to be coordinated with the reef location.

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